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Effect of H^\pm on $D_s^\pm \rightarrow \mu^\pm \nu_\mu$ and $D_s^\pm \rightarrow \tau^\pm \nu_\tau$

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Abstract

We investigate the effect of a charged Higgs boson (H^\pm) on the decays $D_s^\pm \rightarrow \mu^\pm \nu_\mu$ and $D_s^\pm \rightarrow \tau^\pm \nu_\tau$, which will be measured with high precision at forthcoming CLEO-c. We show that a H^\pm can suppress the branching ratios by $10\% \rightarrow 15\%$ from the Standard Model prediction, and we emphasize that such contributions should not be overlooked when comparing lattice calculations of f_{D_s} to the values obtained from these decays.

Keywords : Rare D decay

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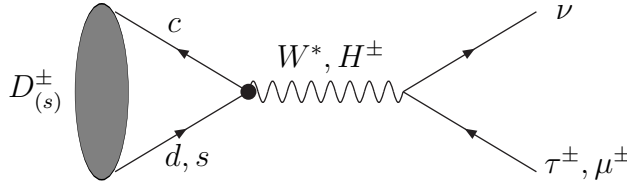
1 Introduction

Purely leptonic decays are the classic ways to measure the decay constants (f_P) of charged pseudoscalar mesons P^\pm . For the light mesons, π^\pm and K^\pm , the muonic decays $\pi^\pm \rightarrow \mu^\pm \nu_\mu$, $K^\pm \rightarrow \mu^\pm \nu_\mu$ have large branching ratios (BRs) and so their respective decay constants have been determined with high precision [1] ($< 1\%$). For the charmed pseudoscalar mesons (D^\pm , D_s^\pm) the BRs for the purely leptonic channels are much smaller than those for the above light mesons due to the dominance of weak decay mechanism $c \rightarrow W^\pm q$ with a spectator quark. These smaller leptonic BRs together with the lack of a dedicated charm factory has resulted in vastly inferior experimental precision for the charmed meson decay constants compared to that for f_π and f_K . Current measurements of f_D and f_{D_s} have large errors of around 100% and 15% respectively [1]. With the imminent (summer 2003) commencement of the CLEO-c experiment [2] this situation will improve dramatically in the next 2 \rightarrow 3 years. Precise $\mathcal{O}(1 \rightarrow 2\%)$ measurements of f_D and f_{D_s} are expected and will constitute a vital test of lattice methods for the heavy quark systems, as well as providing crucial experimental input for calculations of the B meson decay constants [2].

However, absent in the above discussion is the fact that the leptonic decays of D^\pm and D_s^\pm might be affected by physics beyond the Standard Model (SM). It is known that new charged particles which couple to the fermions would contribute at tree-level to these decays [3]. One such example is a charged Higgs boson H^\pm , and in this paper we consider its effect on the decays $D_s^\pm \rightarrow \mu^\pm \nu_\mu$, $D_s^\pm \rightarrow \tau^\pm \nu_\tau$, and thus the measured value of f_{D_s} . We point out that the possibility of such new physics contributions to these decays should not be overlooked when comparing the experimentally measured value of f_{D_s} to the lattice QCD predictions.

2 The decays $D_s^\pm \rightarrow \mu^\pm \nu_\mu$ and $D_s^\pm \rightarrow \tau^\pm \nu_\tau$

Singly charged Higgs bosons, H^\pm , arise in any extension of the SM which contains at least two $SU(2) \times U(1)$ Higgs doublets, e.g. any Supersymmetric (SUSY) model. Together with W^\pm they mediate the leptonic decays $D_{(s)}^\pm \rightarrow l^\pm \nu_l$ via the annihilation process shown below:



The tree-level partial width is given by [3]:

$$\Gamma(D_{(s)}^\pm \rightarrow l^\pm \nu_l) = (G_F^2/8\pi) m_{D_{(s)}}^2 m_l^2 f_{D_{(s)}}^2 r_{(s)} |V_{cd(cs)}|^2 \left(1 - m_l^2/m_{D_{(s)}}^2\right)^2 \quad (1)$$

where m_l is the mass of the lepton, $m_{D_{(s)}}$ is the mass of the $D_{(s)}^\pm$ meson, $V_{cd(cs)}$ are CKM matrix elements, and

$$r_{(s)} = [1 - \tan^2 \beta (m_{D_q}^2/m_{H^\pm}^2)(m_q/m_c)]^2 = [1 - R^2 m_{D_q}^2 (m_q/m_c)]^2 \quad (2)$$

Decay	SM BR	Current Exp BR	Exp Error	CLEO-c Error
$D^\pm \rightarrow \mu^\pm \nu_\mu$	$4.5 \pm 0.6 \times 10^{-4}$	$8_{-5-2}^{+16+5} \times 10^{-4}$	$\sim 100\%$	3.8%
$D_s^\pm \rightarrow \mu^\pm \nu_\mu$	$5.2 \pm 1.2 \times 10^{-3}$	$5.3 \pm 0.9 \pm 1.2 \times 10^{-3}$	25%	3.2%
$D_s^\pm \rightarrow \tau^\pm \nu_\tau$	$5.1 \pm 1.2 \times 10^{-2}$	$6.1 \pm 1.0 \pm 0.2 \times 1.3 \times 10^{-2}$	25%	2.4%

Table 1: SM predictions, current experimental BR, experimental error and CLEO-c expected errors for certain leptonic decays of D^\pm and D_s^\pm

where $r_{(s)} = 1$ in the SM, $R = \tan \beta / m_{H^\pm}$ and $\tan \beta = v_2 / v_1$ (ratio of vacuum expectation values). The H^\pm contribution interferes destructively with that of W^\pm , causing a suppression in the BR, with the largest deviations arising for large R . For D^\pm this effect is essentially negligible ($r \approx 1$) due to the smallness of m_d / m_c , but for D_s^\pm the scaling factor r_s may differ from 1 due to the non-negligible m_s / m_c . This has been noted before [3], [4] but a numerical study was absent. In light of the high precision expected in the measurement of these leptonic decays at CLEO-c, we wish to quantify the previous qualitative analyses in order to see if the H^\pm contribution can be significantly larger than the anticipated error in the measurement of $\text{BR}(D_s^\pm \rightarrow \tau^\pm \nu_\tau, \mu^\pm \nu_\mu)$.

The current experimental measurements and the SM predictions for the three leptonic decays which CLEO-c expects to measure are given in Table 1. For the SM predictions we take the lattice results $f_D = 226 \pm 15$ MeV and $f_{D_s} = 250 \pm 30$ MeV [5], which induces an error of around 15% \rightarrow 25% the BRs. The measurements of the D_s^\pm decays are world averages taken from Ref. [6] and that for $D^\pm \rightarrow \mu^\pm \nu_\mu$ is taken from Ref. [7]. The expected errors from CLEO-c are shown in the final column.

3 Numerical Results

We now quantify the effect of the H^\pm contribution on r_s (eq.2). For the quark masses m_s and m_c we use the Particle Data Group values [1] and obtain $0.06 < m_s / m_c < 0.15$. The value of $R (= \tan \beta / m_{H^\pm})$ is best constrained from non-observation of the decay $B^\pm \rightarrow \tau^\pm \nu_\tau$, giving $R < 0.34 \pm 0.02 \pm 0.06 \text{ GeV}^{-1}$, where the first error is from f_B and the second is from possible large SUSY corrections [10]. Thus we take $R = 0.4 \text{ GeV}^{-1}$ as our largest value.

In Fig.1 we plot r_s as a function of R for various values of m_s / m_c . For $R = 0.4$ one has $r_s = 0.83(0.93)$ for the largest (smallest) values of m_s / m_c . This suppression is comfortably larger than the anticipated experimental error of 2% \rightarrow 3% (shown by the horizontal line) in the measurement of $\text{BR}(D_s^\pm \rightarrow \tau^\pm \nu_\tau, \mu^\pm \nu_\mu)$. Thus the presence of H^\pm would lead to a deceptive smaller *measured* value of the decay constant f_{D_s} . This effect was pointed out for the case of f_K in Ref. [3], where $\text{BR}(K^\pm \rightarrow \mu^\pm \nu_\mu)$ can be suppressed by a factor comparable to that for the $m_s / m_c = 0.06$ curve. Although the effect of H^\pm is less than the 25% error in $\text{BR}(D_s^\pm \rightarrow \mu^\pm \nu_\mu, \tau^\pm \nu_\tau)$ from the current lattice predictions of f_{D_s} [5], there are already signs that the error in f_{D_s} will be significantly improved in the near future. A recent paper [8] calculated f_{D_s} with a precision of 4% (252 ± 9 GeV) in the quenched approximation, while the techniques discussed in Ref. [9] promise comparable or smaller errors in the unquenched

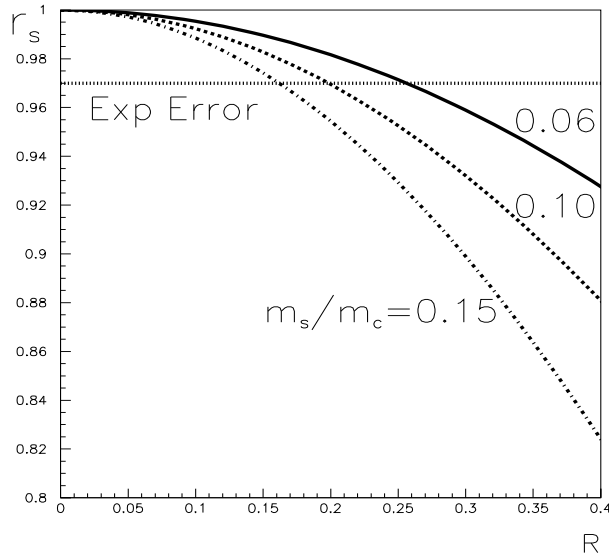


Figure 1: r_s as a function of $R(= \tan \beta / m_{H^\pm})$, for various values of m_s/m_c

approximation. With these anticipated reductions in the theoretical error of f_{D_s} , we suggest that the possible effects of any H^\pm should not be overlooked when comparing the experimentally extracted f_{D_s} to the prediction from lattice QCD.

An additional observable which will also be a test of lattice QCD is the ratio of the muonic decay rates \mathcal{R}_μ defined by

$$\mathcal{R}_\mu = BR(D_s^\pm \rightarrow \mu^\pm \nu_\mu) / BR(D^\pm \rightarrow \mu^\pm \nu_\mu) \sim (f_{D_s}/f_D)^2 \quad (3)$$

The lattice prediction for f_{D_s}/f_D is known with substantially greater precision than the individual values of the decay constants, and currently stands at 1.12(4) for unquenched calculations and 1.12(2) in the quenched approximation [5], i.e. an error $< 4\%$. A similar ratio (\mathcal{R}_τ) for the decays $D_{(s)}^\pm \rightarrow \tau^\pm \nu_\tau$ is also potentially an experimental observable, but is unlikely to be measured in the foreseeable future since CLEO-c has limited sensitivity to $D^\pm \rightarrow \tau^\pm \nu_\tau$ [2]. Hence we will only consider \mathcal{R}_μ , whose current SM prediction is given by $\mathcal{R}_\mu = 12 \pm 0.8$, i.e. $\sim 7\%$ error. The current experimental measurement of \mathcal{R}_μ is based on 1 event for $BR(D^\pm \rightarrow \mu^\pm \nu_\mu)$ [7], whose central value is consistent with the old MARKIII limit of $BR(D^\pm \rightarrow \mu^\pm \nu_\mu) < 7.2 \times 10^{-4}$ [12]. Using the latter, a current lower bound would be $\mathcal{R}_\mu > 7 \pm 2$. The first accurate measurement of \mathcal{R}_μ is expected at CLEO-c with an error of around 7%, which is roughly the same as the error in the lattice prediction for \mathcal{R}_μ . In contrast, in the case of the individual BRs the current theoretical error is substantially larger than the expected experimental error. The presence of H^\pm would modify \mathcal{R}_μ by the factor r_s . Since the expected theoretical error in \mathcal{R}_μ should approach the percent level or less, \mathcal{R}_μ may also be a sensitive probe of physics beyond the SM. As an example, in SUSY models with R Parity violating slepton interactions, $BR(D^\pm \rightarrow \mu^\pm \nu_\mu)$, which is essentially unaffected by H^\pm , can be significantly suppressed or enhanced by the cou-

pling combination $\lambda_{232}\lambda'_{221}$, as discussed in Ref. [11]. Thus the presence of these couplings would give rise to a larger \mathcal{R}_μ ($\gg 12$) or allow values close to the current experimental limit ($\mathcal{R}_\mu \approx 7$) depending on the sign and magnitude of the product of R Parity violating couplings $\lambda\lambda'$. Thus the first measurements of R_μ from CLEO-c are eagerly awaited.

Finally we note that any sizeable effects of H^\pm on $\text{BR}(D_s^\pm \rightarrow \mu^\pm \nu_\mu, \tau^\pm \nu_\tau)$ and \mathcal{R}_μ should manifest themselves in the purely leptonic B^\pm decays, $B^\pm \rightarrow \tau^\pm \nu_\tau, \mu^\pm \nu_\mu$. This is because r_s depends strongly on $R(= \tan \beta / m_{H^\pm})$, whose permitted value is constrained from the upper limits on the above B^\pm decays. The B factories will be sensitive to $R \sim 0.25$ with 400 fb^{-1} , and thus any significant suppression in r_s from H^\pm would be accompanied by a corresponding enhancement in $B^\pm \rightarrow \tau^\pm \nu_\tau$ (and $\mu^\pm \nu_\mu$).

4 Conclusions

We have studied the effect of a H^\pm on the leptonic decays $D_s^\pm \rightarrow \mu^\pm \nu_\mu, \tau^\pm \nu_\tau$. We showed that H^\pm can suppress the BRs by up to 10% \rightarrow 15%, which is larger than the expected experimental error (2% \rightarrow 3%) from CLEO-c. We suggested that new physics effects like these should not be overlooked when comparing the experimental measurements of f_{D_s} to the SM lattice QCD predictions.

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